Assigned Proposal Number: ___

Strategic Initiative Proposal for the
Research and Technology Development Fund for FY2005

Due Date: Friday, June 18, 2004 at 5:00 pm PDT

1. Title of Proposal

Distributed Rover Avionics Software

2. Investigator (First Last) - Section **Petras, Richard**	**3. Co-Investigators (First Last) - Section** **Nesnas, Issa** **Watson, Kevin**
4. Budget (check one box) **New Proposal [x]** **Renewal [ ]** **FY05: $400K** **FY03:** **FY06:** **FY04:** **FY07:** **FY05:** **FY06:**	
5. Technology Readiness Levels (if applicable) **Starting TRL (1-9): 4** **Anticipated TRL (1-9):5**	**6. Check Box if Field Work/Testing is Required [ ]**

7. Strategic Initiatives (check one box)

Large Apertures & Advanced Optics:
[ ] Large Apertures and Precision Wavefront Control
[ ] Advanced Optics Modeling & Simulation (IMOS)

Detectors & Sensors:
[ ] Far-IR and Sub-mm Sensors
[ ] Nanotechnology for Instruments
[ ] Instrument Cryocoolers (subk to 4k)

In-Situ Planetary Exploration:
[x] Planetary Mobility
[ ] Science Operations on Planetary Surfaces
[ ] In Situ & Life Detection Measurement Systems

Planetary Protection:
[ ] Planetary Protection Systems

Survivable Systems:
[ ] Technologies for Extreme Environments
[ ] Survivability of COTS in High-Radiation Environments

Deep Space Communications:
[ ] Spacecraft Systems for 100x RF Communications
[ ] Reception Systems for 100x RF Communications
[ ] Outer Planet Optical Communications

Deep Space Navigation:

Systems Engineering:
[ ] Advanced System Engineering

High Capability Computing:
[ ] Software Techniques and Methodologies
[ ] High Capability Computing in Engineering & Science
[ ] Computing, Modeling, Simulation, and Visualization

Planetary Science:
[ ] Chemistry and Physics of Planetary Ices

Earth Science:
[ ] Solid Earth: GPS, Gravity, InSAR
[ ] Climate Change
[ ] L1 Spacecraft and Detectors for Atmospheric Chemistry

Astronomy & Physics:
[ ] Dark Energy Science
[ ] Interferometry Science

Renewals Only (no new proposals):
[ ] High Capability Instruments
[ ] Avionics for Mobility
[ ] Icy Body Landers
[ ] Long Wavelength Astrophysics & Gravitational Physics
[ ] Formation & Evolution of Planetary Systems

[ ] Small Body Guidance, Navigation, and Control

8a. General Objectives (Abstract): (Clearly and concisely state the proposal objectives and goals and what are the expected deliverables/products of the proposed work and why these are important technically and programmatically.)

The objective of the work described in this proposal is to demonstrate autonomous rover navigation software running on a distributed processor system. ~~The intent of this work~~ will ~~be to~~ use existing rover hardware and software but to demonstrate improved performance and modularity by distributing the processing across multiple CPUs. This task will investigate the proper workload balancing between processors. We will study the trade off between local processing and bus bandwidth and latency requirements. And we will develop the necessary communication and coordination mechanisms or select existing communications protocols for interprocessor communications. The software developed by this task will be developed in the context of the CLARAty software architecture. This will not only make the software available for reuse by other JPL tasks, it will provide the necessary constructs to allow CLARAty to be used in a multiprocessor and potentially multi-rover environment.

This task intends to use the Micro Avionics Modules developed by the existing Advanced Mobility Avionics R&TD task. The Mars Technology Program has a task that is building the PLUTO rover based on these avionics modules. We will demonstrate autonomous navigation on the PLUTO rover avionics package. The software modules and components developed by this task will be delivered as components of the CLARAty software architecture.

The Advanced Mobility Avionics task is providing JPL with modular reconfigurable avionics hardware. CLARAty is providing JPL with modular, reusable software. This task will allow the two to be easily combined so that JPL has a complete set of avionics hardware and software that is modular, reusable and reconfigurable.

8b. Quantitative Objectives: 1) Discuss quantitative capability goal of proposal 2) Compare with current capability both at JPL and outside JPL.

Existing rover avionics for the most part depend on a centralized computer hardware model. A central processor controls all sensors and actuators with control interfaces attached directly to the main computer bus inside the main electronics enclosure. All of the wiring for all external sensors and actuators then must be routed to the central processor. The purpose of the Mobility Avionics task was to produce a processor that was powerful enough to support local control of the sensors and actuators while allowing control across a lightweight local bus with a simple command and power interface. Rovers such as the MER rover moved in the direction of local control by moving motor control onto FPGA motor controllers thus reducing some of the processor load, but they are still centrally located and do not necessarily help reduce wiring mass. The Rocky 8 research rover is an example of a distributed architecture, but this is a heterogeneous architecture with a powerful central processor and less capable distributed processors. The MSL rover will also have a distributed processor motor controller and intelligent instruments with a powerful central processor. The trend is to move more of the intelligence out into the peripherals.

This task will provide the infrastructure for software modules to communicate with distributed processors that ~~are capable of~~ running software and operating systems that are the same ~~or similar to~~ the operating system in the main processor. In the case of the PLUTO rover, the main processor will be a Micro Avionics Module (See Figure 1).

The CLARAty software architecture has been crafted to allow for the communication between modules across processors, however until now no hardware platforms have existed that would allow a demonstration of this capability.

In fact, the mechanism to provide communication between software modules is not part of the CLARAty architecture. There are existing communications mechanisms such as CORBA, TAU and DDS. This task will investigate which, if any, of these are applicable to real-time control in multiprocessor systems.

The Advanced Mobility Avionics task has demonstrated CLARAty locomotion and vision code running on a single Micro Avionics Module, and it intends to port several vision algorithms to the FPGA hardware. By providing the mechanisms to allow parallel execution of code in multiple processors and intercommunication between processors, this task will provide the capabilities that enable distributed and redundant processing using multiple Micro Avionics Modules.

9. For New Proposals Only: Approach: Describe how you plan to achieve your objectives. Give specific tasks and milestones that will be accomplished.

This task would leverage work already done by the Advanced Mobility Avionics task and the CLARAty task by using existing hardware and existing software development environments and code. The Micro Avionics Module will be included in CLARAty as a supported target for software development.

Initial work will begin with the selection of one or more communications protocols to communicate between CLARAty modules. Software modules consists of code to perform ~~the various rover functions~~ from high level functions like navigation to low level functions like motor control. When a functional layer module like motor control runs in a separate processor it will be wrapped in a motor control commander wrapper that allows a remote motor controller module to interface to it. (See figure 1) The communication mechanism used will depend on the bandwidth and latency requirements. Whether we use a standard protocol like CORBA, DDS or just TCP sockets and whether we can use the same protocol for all of the interfaces will be one of the objectives of this task. This selection will depend on the interconnection bus bandwidth, allowable real-time latency and the selection of the functional breakdown of the software across processors.

One of the results of the initial work will be the selection of the functional breakdown of the software running on each processor. The task will demonstrate at least three processors running in parallel with one processor dedicated to capturing and processing stereo images, the second dedicated to wheel motor control and the third coordinating navigation. There are many possible ways to divide the processing of these tasks. For example, vision processing could entail creating a disparity map and passing that back to the navigation processor. Or it could create a range map which might offload the navigation processor at the expense of higher bandwidth. Or it could process the images all the way down to an obstacle map. This would completely offload vision processing from the navigation processor, but might overload the vision processor. The same thought process would have to be done for motor actuation. Should all of the locomotion kinematics go in the motor control processor, or does this belong in the navigation processor?

Once these issues are resolved, the task will demonstrate control of the various modules across processors. Actual timing results and bandwidth measurements will be gathered. Initial testing of parallel execution of commands across the bus will be made. A demonstration of the GESTALT or Morphin navigation algorithm running on the multiprocessor PLUTO rover will complete the integration task.

Q1 2005
- Micro Avionics Module software development testbed installed
- Software functional breakdown selected
- Interprocessor communication protocols selected

Q2 2005
- Vision processor remote commander implemented

Q3 2005
- Motor controller remote commander implemented

Q4 2005
- Demonstration of multiprocessor autonomous navigation
- Final delivery of multiprocessor code to CLARAty repository

10. For Renewal Proposals Only: Discuss the specific accomplishments you achieved in FY04. Give specific tasks and milestones that will be accomplished.

11. Relevance to Strategic Initiative: Explain the relevance of your work to the initiative Describe the advantages of this approach

Upon completion this task will provide JPL with a library of software that enables multiprocessor communication. This will allow parallel processing, or redundant processing when used inside a single vehicle. When combined with wireless network technology it will even allow multi-rover communication. On the Micro Avionics Modules it will allow JPL to build combined hardware and software modules that provide standard functionality and interfaces that can be used off the shelf. For example, a vision processing module would consist of a Micro Avionics Module, two cameras and the necessary vision code. When added to a network, it would present a standard interface at a certain port and IP address. It would then just require interfacing with the corresponding remote interface module from the software library. In the same way standard instrument, sensor and actuator modules could be built that include both hardware and software.

A large body of MTP developed software already exists. By incorporating the Micro Avionics Modules into the existing software development environment, it allows hardware designers to take advantage of existing software for initial testing and integration.

Micro Avionics Modules can provide the same capabilities as standard spacecraft processors, but at much lower power and weight. By enabling them to be used in a multiprocessor configuration, either more processing power or more redundancy can be added to an avionics system while still reducing power and weight when compared to standard avionics packages.

12. What strengths do the team members bring to this proposal? Are all technical areas covered?

PI – Richard D. Petras (JPL)

Rich has over 20 years of experience in software engineering and space systems design. He is co-investigator and software lead for the Advanced Mobility Avionics task. He was a founding member of CLARAty team, and as a member of that team was cognizant engineer for the Rocky 7 and Rocky 8 rovers. **He is a member of the** MER Mobility and IDD downlink operations team and was instrumental in testing the MER Autonomous navigation software. He will be lead software engineer for the task.

Co-I – Dr. Issa A.D. Nesnas (JPL)

Issa **has over ten years of experience in the field of research and industrial robotics. He is the principal investigator for the CLARAty Architecture task which has been adapted to Rocky 8, FIDO, Rocky 7, K9, Dexter and ATRV robots. He is the principal investigator on the Axel rovers and been integral in the development of the Rocky 8 and Rocky 7 hardware. He has received several awards for his work at JPL. Dr. Nesnas will be responsible for providing technical support on distributed computing and ensuring consistency with the CLARAty architecture.**

Co-I – R. Kevin Watson (JPL)

Kevin has over ????? years experience... He is co-investigator for the Advanced Mobility Avionics task and its electronic design lead....

13. Significance and impact of results on JPL's technical capabilities and on future missions and programs

By providing multiprocessor functionality to Micro Avionics Modules, this software will realize the benefits of a distributed hardware design, including: increased computation speed, reduced integration cost, and system redundancy. ***This will drive down rover mission costs, while increasing capability.***

Software work done by Advanced Mobility Avionics task will be made modular and reusable and put on the path to flight through integration with CLARAty.

14. Describe plans for seeking direct follow-on funding **This technology applies to work being done in the MTP, Code T. and possibly DARPA. Missions such as MSL, MSR and other missions could use the software and the multiprocessor capabilities enabled by this software for instrument, sensor and actuator processors, or as coprocessors for algorithms that are computationally expensive.**	**15. Who in the program office have you spoken to about this proposal and in what program office?** **Richard Volpe (665)**
16. Budget FY05 Direct Costs **(The R&TD tasks are reported on a Direct Cost ("Raw Cost + Fringe Benefits") basis. As a result, no other burdens are shown.)**	
a. JPL Labor (itemize) **(You only need to "itemize" the person names (or job classifications) and the number of hours for each. You can show one total $ JPL salary figure for labor.)**	**PI - 0.75** **Co-I – 0.25** **Co-I – 0.25** **Additional JPL staff hours – 1.5** **$245,000**
b. Labor Fringe (multiply total JPL Labor $ figure in line a. by the 49.3% labor fringe rate)	**$120,000**
c. Cat-A Labor (itemize) **(On-Lab contractors)**	**$0**
d. On-Lab Post-Doc Support (itemize) **(Post-Docs who will perform work at JPL)**	**$0**
e. Procurement -- Equipment (itemize) **(All proposed equipment costs must be itemized here)**	**3 @ $5000 Micro Avionics Modules – For software development testbed** **$15000**
f. Procurement -- Other (itemize) **(materials and supplies, etc.)**	**$0**
g. Procurement -- Subcontracts (itemize)	**$0**
h. Services (itemize) **("in-house" services at JPL)**	**Unix support - $10,000**
i. Travel (only as research cost; no conference or foreign travel is allowed)	**$0**
j. Other (itemize) **(Chargebacks, etc.)**	**Chargebacks - $ 10,000**
	$400,000

k. TOTAL (sum of lines a. through j.)	
17. PI Division Manager Approval Signature **Name:** **Org:**	
18. Initiative Leader Approval Signature **Name:** **Initiative:**	
19. Principal Investigator Signature	

Figures, Graphics, Tables, etc.

(Please do not use "text-wrapping" when incorporating graphics at the end of the report.)

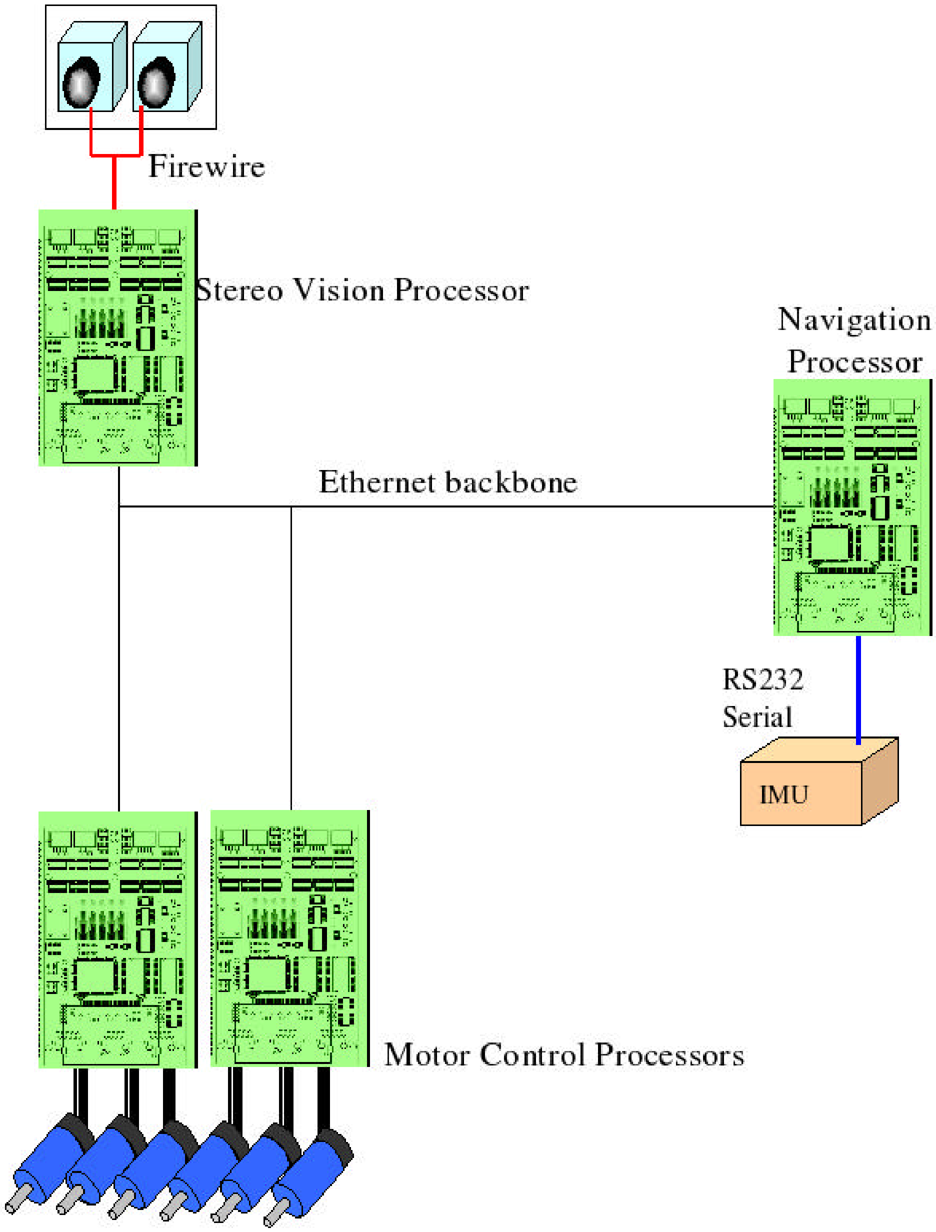
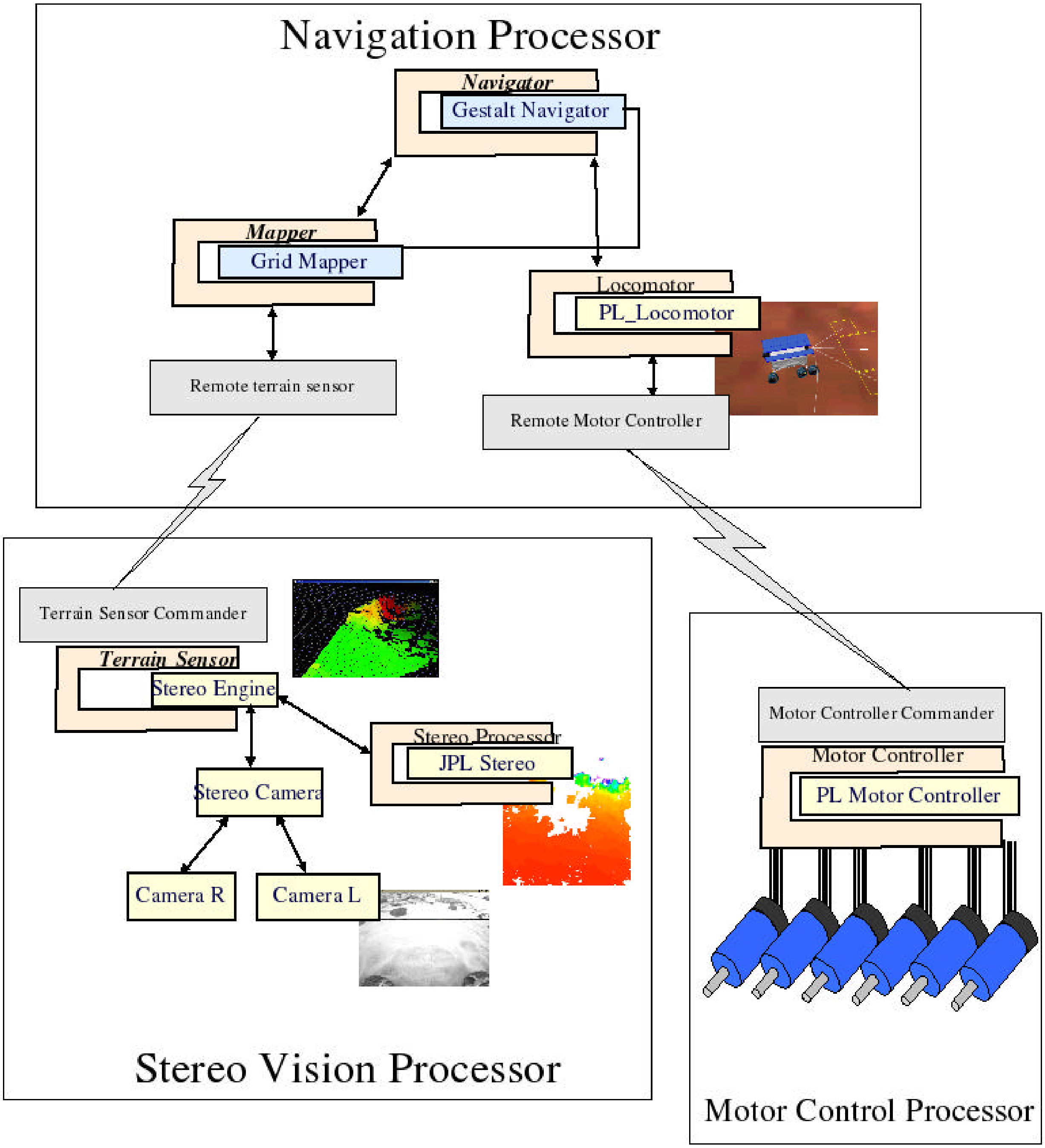


Figure 1. Pluto Rover Module Configuration



Navigation Processor
Navigator
Gestalt Navigator
Mapper
Grid Mapper
Locomotor
PL_Locomotor
Remote terrain sensor
Remote Motor Controller
Terrain Sensor Commander
Terrain Sensor
Stereo Engine
Stereo Processor
JPL Stereo
Stereo Camera
Camera R
Camera L
Stereo Vision Processor
Motor Controller Commander
Motor Controller
PL Motor Controller
Motor Control Processor

Figure 2. Remote modules.